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HEAT-TRANSFER TESTS ON A FULL AND 1/4 SCALE AIM-9E SIDEWINDER MISSILE AND A 1/15 SCALE GBU-8 GUIDED BOMB UNIT AT MACH NUMBERS OF 1.5, 2.0 AND 2.5

W. K. Crain
ARO, Inc.

October 1979

Final Report for Period June 1979 through August 1979

ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

APPROVAL STATEMENT

This report has been reviewed and approved.

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FOR THE COMMANDER

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Deputy for Operations

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Heat transfer tests were conducted in the Arnold Engineering Development Center (AEDC) Supersonic Wind Tunnel A on a 1/4 and full scale AIM-9E Sidewinder Missile and a 1/15 scale GBU-8 Guided Bomb Unit. The purpose of the tests was to obtain heating distributions on the stores for wind tunnel/flight correlation and as baseline data for input to an analytic thermal response code. Heat transfer coefficient, adiabatic wall temperature, and Schlieren/shadowgraph photographic data were obtained. Tests were conducted at Mach numbers 1.5,

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20. ABSTRACT (Continued)

2.0 and 2.5 and free-stream unit Reynolds numbers of 1×10^6 to 5×10^6. Model angle of attack was varied over the range from -2 to 4 degrees. In addition, performance evaluation tests were conducted on a stand-alone flight data system designed to gather flight test heat-transfer data.

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NOMENCLATURE

AO	Intercept of linear curve fit [see Eq. (7)]
A1	Slope of linear curve fit [see Eq. (7)]
ALPHA	Model angle of attack, deg
ALPI	Indicated pitch angle, deg
C1	Gardon gage calibration factor measured at 530°R, Btu/ft^2-sec/mv
C2	Temperature corrected Gardon gage calibration factor, Btu/ft^2-sec/mv
E	Gardon gage output, mv
GAGE	Gardon gage identification number
HFR	Reference heat-transfer coefficient (see Appendix IV)
H(TAW)	Heat-transfer coefficient based on TAW, Q DOT/(TAW-TW), Btu/ft^2-sec-°R
ITAW	Enthalpy based on TAW, Btu/lbm
ITW	Enthalpy based on TW, Btu/lbm
KG	Gardon gage temperature calibration factor, °R/mv
LM	Model reference length, in. 118.0 for AIM-9E full scale 29.565 for AIM-9E 1/4 scale 9.930 for GBU-8
M, MACH	Free-stream Mach number
MU	Dynamic viscosity based on free-stream temperature, lbf-sec/ft^2
MUTT	Dynamic viscosity based on TT, lbf-sec/ft^2
P	Free-stream static pressure, psia
PHI, ROLL	Model angle of roll, deg
PHII	Indicated roll angle, deg

PT	Tunnel stilling chamber pressure, psia
PT2	Total pressure downstream of a normal shock wave, psia
Q	Free-stream dynamic pressure, psia
QDOT	Heat-transfer rate, Btu/ft^2-sec
RN	Nose radius, in. 1.40 inches (Full Scale AIM-9E) 0.35 inches (1/4 Scale AIM-9E) 0.327 inches (1/15 Scale GBU-8)
RE	Free-stream unit Reynolds number, ft^{-1}
REX	Reynolds number based on free-stream conditions and the distance X (X measured from model nose to a particular gage)
RHO	Free-stream density, lbm/ft^3
RUN	Data set identification number
STFR	Stanton number based on reference conditions (see Appendix IV)
ST(TAW)	Stanton number based on TAW, ST(TAW) = QDOT/[(RHO)(V)(ITAW - ITW)]
ST(TAW)0	Stanton number based on heat-transfer coefficient from the model stagnation heat transfer gage
T	Free-stream static temperature, °R
TAW	Adiabatic wall temperature, °R
TGE	Gardon gage edge temperature, °R
THETA	Angular measurement on model, deg
TT	Tunnel stilling chamber temperature, °R
TW	Wall temperature of a Gardon gage, °R

ΔT	Temperature differential across the Gardon gage disc, °R or °F
V	Free-stream velocity, ft/sec
X	Axial distance from nose, in.

1.0 INTRODUCTION

The work reported herein was conducted at the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), by ARO, Inc., AEDC Group (a Sverdrup Corporation Company), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee. This work was done in support of the Store Heating Technology Project sponsored by the Aircraft Compatibility Branch, Air Force Armament Test Laboratory (AFATL), Eglin AFB, Florida, under Program Element 62602F, Control Number 2567-00-9. The AFATL project monitor was Capt. Spence Peters.

The test objective was to obtain heating distributions on the full scale AIM-9E, 1/4 scale AIM-9E and the 1/15 scale GBU-8. A secondary objective was to record heat-transfer rate and model temperature data on the DCAP* flight data recorder for the purpose of evaluating the performance of this system. The heat-transfer data obtained on the AIM-9 models will be used in conjunction with flight test data to develop wind tunnel to flight scaling procedures. A flight test program is planned to obtain data on the AIM-9E/DCAP unit in FY80. The GBU-8 data are to be used as inputs for analytical calculations of store internal component temperature response.

The tests were conducted in two phases. Both test entries were run in the von Kármán Gas Dynamics Facility (VKF), Supersonic Wind Tunnel (A) under ARO Project Number V41A-48. The 1/4 scale AIM-9E and the 1/15 scale GBU-8 were tested in Phase A during the period of June 6-7, 1979. The full scale AIM-9E/DCAP hardware was tested in Phase B during the time period of July 27-28, 1979. Data were recorded at Mach numbers 1.5, 2.0 and 2.5 at a tunnel stagnation temperature of 180°F. Oil flow runs on the 1/4 scale AIM-9E were made at a tunnel stagnation temperature of 100°F. Free-stream unit Reynolds numbers ranged from 1.0×10^6 to 5.0×10^6 per foot. Model angle of attack was varied from -2 to 4 deg on the AIM-9E models. Data were obtained with and without canards and launch rail as well as with and without boundary layer trips.

The GBU-8 model was tested at angles of attack of 0 and 4 degrees and roll angles of 0, ±90, and 180 degrees. This model was also tested with and without boundary layer trips.

Copies of the Phase A results have been transmitted to AFATL/DLJC. Copies of the Phase B results will be transmitted to AFATL as well as copies of this report. Inquiries to obtain copies of the test data should be directed to AFATL/DLJC, Eglin Air Force Base, Florida. A copy of the final data has been retained on microfilm at Arnold Engineering Development Center in the von Kármán Gas Dynamics Facility.

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*DCAP = Acronym for Data Correlation and Acquisition Project flight data recorder (Ref. 1).

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel A (Fig. 1) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel can be operated at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 750°R at Mach number 6. Minimum operating pressures range from about one-tenth to one-twentieth of the maximum at each Mach number. The tunnel is equipped with a model injection system that allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel and airflow calibration information may be found in Ref. 2.

2.2 TEST ARTICLES

2.2.1 AIM-9E

The hardware tested represented the forward 36 percent of the AIM-9E Sidewinder missile and WSE Pod* (Fig. 2). In addition, the AERO-3B Launcher was used to provide missile launch rail influence on the measured heating distributions. The test hardware was composed of a full and 1/4 scale model (Fig. 3).

Flight hardware obtained from Robbins and Hill Air Force Bases was used for the full scale missile. Modifications to the flight hardware consisted of:

(a) replacing the glass eye used in IR detection with a steel nose dome,

(b) removal of the gas generator in the servo section and of the IR sensor in the guidance section,

(c) installation of heat-transfer gages in the missile skin,

(d) installation of turnbuckles in the servo section as a provision for keeping the canards at zero deflection angle, and

(e) addition of a threaded adaptor to provide transition between the missile forebody and tunnel support system.

Some of these modifications are shown in Fig. 4. In addition, the AERO-3B Launch Rail was cut 37.8 in. aft of the leading edge and installed on the missile at the axial position corresponding to actual flight carriage (Fig. 5).

*WSE = Weapon System Evaluator. WSE is an airborne subsystem used to monitor signals from the aircraft's fire control system to the missile.

A 1/4 scale model of the flight hardware (Figs. 2 and 6) was constructed from stainless steel. The canards were removable but did not possess deflection capability. A simulated AERO-3B Launch Rail was also constructed and was attached to the 1/4 scale model (Fig. 7). The launch rail material was 6061-T6 aluminum alloy.

2.2.2 GBU-8

A 1/15 scale model of the GBU-8 Guided Bomb Unit was tested in conjunction with the 1/4 scale AIM-9E model. A sketch of the GBU-8 is shown in Fig. 8. The model is 9.93 inches long and has fixed cruciform wings. The main body is constructed from 6061-T6 aluminum alloy and the wings from 304 stainless steel. The model and associated support hardware are shown in Fig. 9.

2.3 TEST INSTRUMENTATION

The measuring devices, recording devices, and calibration methods used for all measured parameters are listed in Table 1 along with the estimated measurement uncertainties. Heat-transfer rate measurements were obtained with thermopile Gardon gages which were supplied and calibrated by the VKF. The thermopile gage utilizes vapor-deposited layers of antimony and bismuth to form a thermopile on the back surface of the sensing foil. Gage sizes of 1/4- and 1/8-in. diam were used. The sensing foil thickness on the 1/4-in. diam gages were 0.010 and 0.020 in. while the 1/8-in. diam gages had a foil thickness of 0.005 in. The gages were instrumented on the gage body with copper-constantan thermocouples which provided gage edge temperatures. These temperatures, together with the gage output, were used to determine the gage surface temperatures, which were used to compute the local heat-transfer coefficients.

The full scale missile was instrumented with thirty-five 1/4-in.-diam gages for heat-transfer distribution definition and twenty 1/8-in.-diam gages between canards for defining the shock interaction heating. A sketch showing the general arrangement of the instrumentation is shown in Fig. 10, and dimensional locations of the gages are given in Table 2.

The 1/4 scale AIM-9E and 1/15 scale GBU-8 were both instrumented with 1/8-in.-diameter gages. The 1/4 scale AIM-9E contained 37 gages and the GBU-8, 20 gages. Gage layout for the two models is depicted in Figures 11 and 12. Dimensional locations of the gages are given in Tables 3 and 4 for the 1/4 scale AIM-9E and the 1/15 scale GBU-8, respectively.

Oil flow photographs were taken with Varitron Model E 70-mm cameras mounted on the side of the test section. Two cameras were used to provide photographic data of the fin region of the models. An automatic camera control system was used to provide automatic shutter sequencing in 4-sec intervals.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

The test conditions were selected to provide data on the effects of Reynolds number and Mach number. The following is a summary of the nominal test conditions.

MACH	PT, psia	TT, °R	Q, psia	P, psia	RE x 10^{-6}/ft
1.50	5.1	640	2.19	1.39	1.24
	10.2		4.38	2.78	2.48
	13.4		5.75	3.65	3.26
	14.6		6.26	3.98	3.55
	14.0	559	6.01	3.81	4.07
1.84	4.0	640	1.55	0.66	0.87
2.00	17.0		6.08	2.17	3.45
	18.1		6.47	2.31	3.67
	20.2		7.23	2.58	4.10
	19.5	559	6.98	2.49	4.77
2.38	8.0	640	2.24	0.57	1.35
2.50	23.0		5.89	1.35	3.64
	32.1		8.22	1.88	5.08

At some test conditions, particularly at subatmospheric stagnation pressures, the air humidity level affected the test section Mach number. The Tunnel A sidewall Mach number probe was used periodically when testing at these conditions to monitor deviations from the standard calibrated Mach numbers. When a deviation was measured, the free-stream conditions were corrected and the actual Mach number printed on the data tabulations. Test variables and configurations for the individual runs are presented in Table 5.

Boundary-layer trips were used for all runs with the 1/4 scale AIM-9E and the 1/15 scale GBU-8 models as well as on the low Reynolds number runs on the full scale AIM-9E. The trips consisted of carborundum grit applied to the model with Eastman 910 cement. Number 46 and 70 grit were used on the 1/4 scale AIM-9E and 1/15 scale GBU-8 models while number 150 grit was used on the full scale AIM-9E. Trip locations for the AIM-9E and GBU-8 are depicted in Fig. 13. Grit size for a particular run is listed in the test log (Table 5).

In the VKF continuous-flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. Tunnel installation photographs for the full scale AIM-9E, 1/4 scale AIM-9E and 1/15 scale GBU-8 are shown in Figs. 14, 15, and 16 respectively.

3.1.2 Data Acquisition

Data from the 1/4 scale AIM-9E and the 1/15 scale GBU-8 were recorded exclusively on the Tunnel A standard data system. In the case of the full scale AIM-9E, the DCAP flight data recorder was used in conjunction with the standard data system to record the test data. The purpose of this was to verify the performance of the DCAP system. Gages located so as to give a representative axial heating distribution were routed directly to the DCAP unit. These gages are denoted with an asterisk in Table 2. Of these, five were connected to a quick disconnect plug and were used on the DCAP unit only for the runs dedicated to DCAP evaluation, Runs 47 and 48 (Table 5). These gages are denoted by an asterisk in a circle in Table 2. A description of the DCAP data system is given in Ref. 1.

Procedures for acquiring the test data were as follows. The initial step prior to recording the test data was to cool the model uniformly to approximately 70°F with cooled high pressure air. This was accomplished by providing chilled air from a vortex generator (Hilsch vortex tube, Ref. 3) to a retractable cooling manifold. With the model attitude set at zero pitch the cooling manifold was positioned around the model. When the cooling cycle was complete the manifold was retracted and the model attitude was established prior to tunnel injection. The model was then injected into the flow and immediately translated to the full forward position in the tunnel. At model lift-off the tunnel flow parameters were recorded and the data acquisition sequence for the Gardon gages was initiated prior to reaching the tunnel flow. Data were recorded on 3 to 5 second intervals for each Gardon gage over a period of approximately two minutes until the output of each gage approached zero. The model was then retracted from the tunnel, and the cooling cycle was repeated to cool the model to an isothermal condition.

3.2 DATA REDUCTION

All free-stream parameters were computed assuming a perfect-gas isentropic expansion from the tunnel stilling chamber and utilizing the measured pressure and temperature in the stilling chamber and the calibrated Mach number in the test section.

The thermopile Gardon gages used in the model are direct reading heat flux transducers whose output may be converted to heating rate by means of a scale factor. The thermopile Gardon gage scale factor has been found to be a function of temperature, and therefore must be corrected for gage temperature changes according to the following equation.

$$C2 = C1[4.72878 - (2.83765 \times 10^{-2})(TGE) + (7.82707 \times 10^{-5})(TGE)^2 - (9.44869 \times 10^{-8})(TGE)^3 + (4.30151 \times 10^{-11})(TGE)^4] \quad (1)$$

The heat flux to the thermopile gage can be calculated for any data point by the following equation:

$$QDOT = (E)(C2) \quad (2)$$

The surface temperature of the gage is given by

$$TW = TGE + 0.75\ \Delta T \quad (3)$$

where

$$\Delta T = (KG)(E) \quad (4)$$

A specialized Gardon gage data reduction procedure was used to compute the heat-transfer coefficient. This technique provides a method for extrapolating to adiabatic wall temperature. This is important in Tunnel A where the difference between the model wall temperature and the adiabatic wall temperature is small. This small temperature difference causes the calculation of the heat-transfer coefficient to be sensitive to deviations from the actual adiabatic wall temperature. The special data reduction procedure is based on the concept that

$$H(TAW) = \frac{QDOT}{TAW - TW} \quad (5)$$

where H(TAW) is assumed to be constant. Rearranging Equation (5) gives

$$QDOT = [H(TAW)][TAW] - [H(TAW)][TW] \quad (6)$$

where [H(TAW)][TAW] is a constant. Therefore, Equation (6) can be written in the form of a straight line

$$QDOT = A0 + A1(TW) \quad (7)$$

Since A0 and A1 are constant, a comparison of Equations (6) and (7) gives

$$H(TAW) = -A1 \tag{8}$$

Setting QDOT = 0 in Equation (7) and solving for TW leads to the following relationship:

$$TAW = -\frac{A0}{A1} \tag{9}$$

The actual steps in the data reduction procedure are to obtain a linear curve fit of QDOT versus TW for each gage (a typical plot is shown in Fig. 17) and evaluate A0 and A1 in Equation (7). The quality of the curve fit is verified by examining the plotted data on a graphics display terminal. When the curve fit has been verified, the heat-transfer coefficient can be calculated from Equation (8), and the adiabatic wall temperature can be determined from Equation (9). The value of TAW is checked to see if it is within the following range:

$$0.8 \leq \frac{TAW}{TT} \leq 1.01 \tag{10}$$

If the Equation (10) is not satisfied, an asterisk is printed next to the value of TAW in the tabulated data.

3.3 UNCERTAINTY OF MEASUREMENTS

In general, instrumentation calibrations and data uncertainty estimates were made using methods recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of bias and precision errors defined as:

$$U = \pm (B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation, and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution (95-percent confidence interval), which for sample sizes greater than 30 is taken equal to 2.

Estimates of the measured data uncertainties for this test are given in Table 1a. Data uncertainties for the Gardon gages are determined from laboratory calibrations, and data uncertainties in other measurements are determined from in-place calibrations through the data recording system and data reduction program.

Propagation of the bias and precision errors of measured data through the calculated data was made in accordance with Ref. 4; the results are given in Table 1b.

4.0 DATA PACKAGE PRESENTATION

Heat-transfer coefficients were obtained at selected locations on a full and 1/4 scale AIM-9E Sidewinder Missile, and on a 1/15 scale GBU-8 Guided Bomb Unit. Typical heat-transfer tabulations are illustrated in Appendix III. The data were plotted to present the longitudinal and circumferential distribution of heat-transfer data on the three models.

Representative results from the full and 1/4 scale AIM-9E tests are presented in Fig. 18. The data were taken at free-stream conditions of Mach 1.5 and RE = 5×10^6 per foot. Model angle of attack was zero degrees. The data are plotted in the form $ST(TAW)[RE \times 10^6]^{.17}$ versus X/LM so as to take out any Reynolds number effect.

Heating distribution variation with Mach number is presented in Fig. 19 for the GBU-8. The data were taken at a free-stream unit Reynolds number of RE = 3.6×10^6 per foot and zero degrees angle of attack. In addition, turbulent theory is presented (Ref. 5, MACH = 2.0) indicating that the boundary layer trips were effective in producing a turbulent boundary layer over the model.

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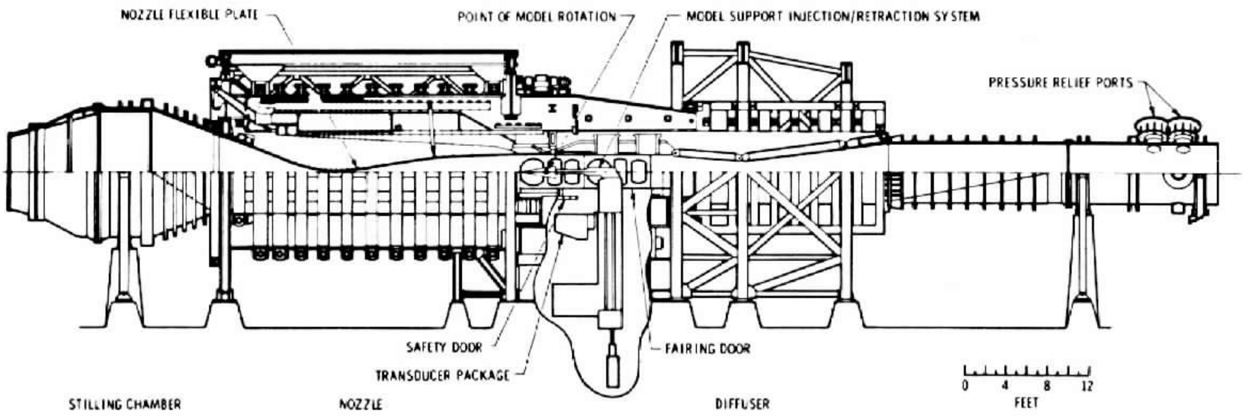
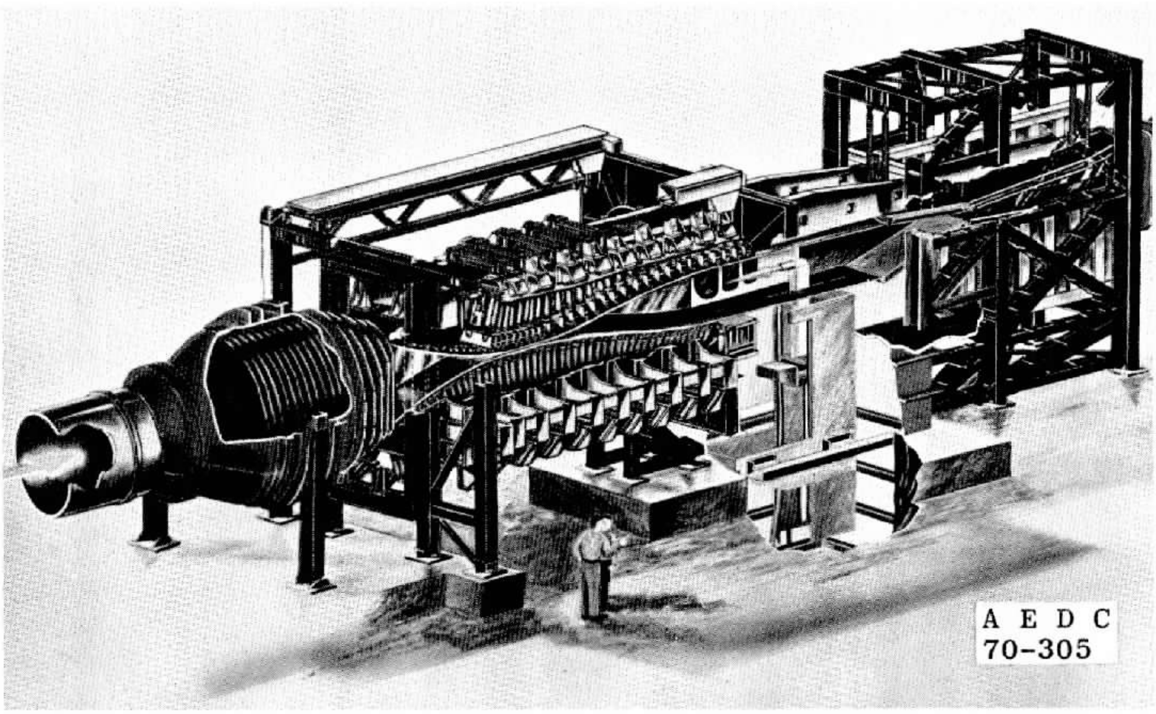
APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section
Fig. 1 Tunnel A

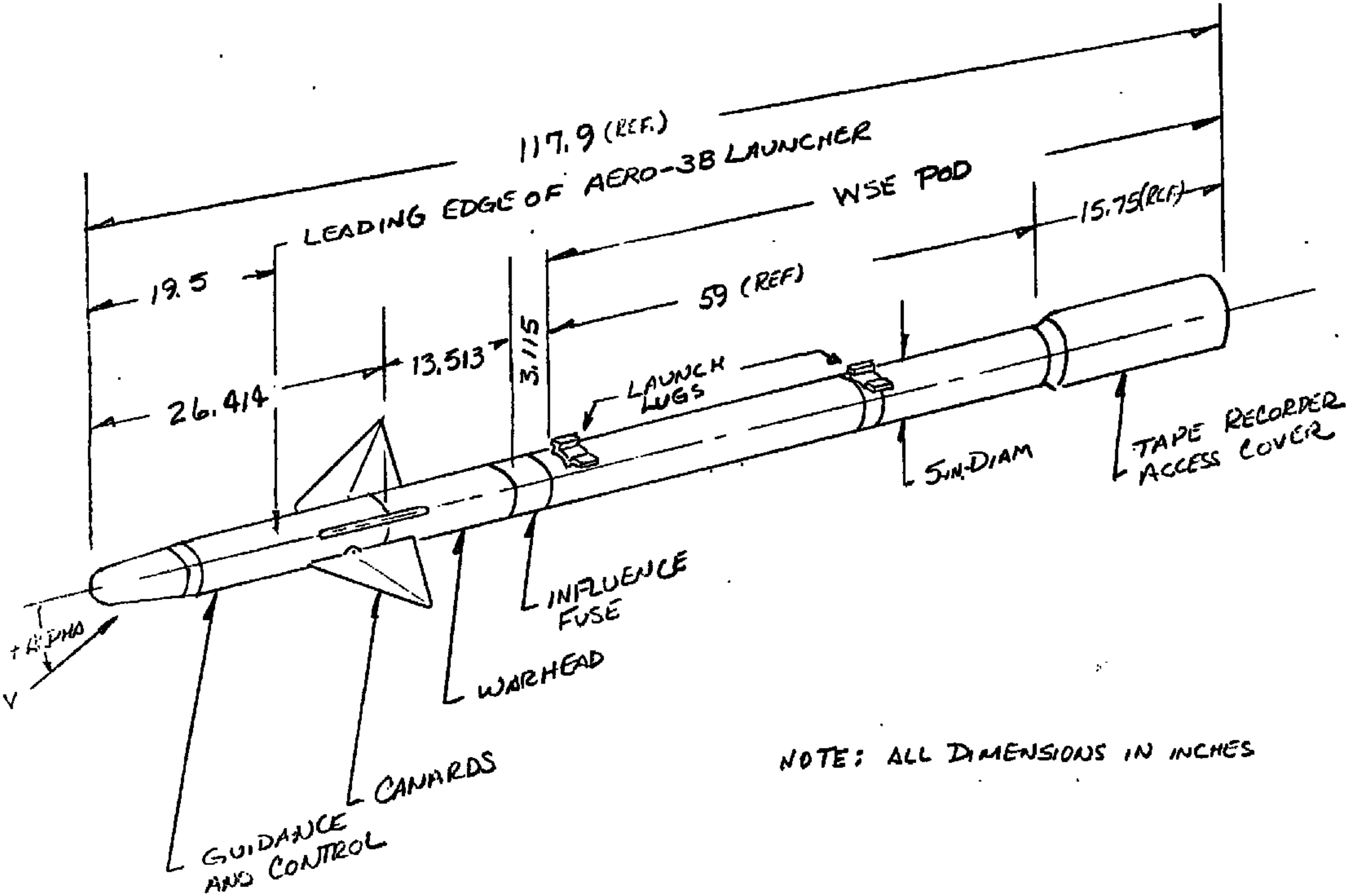


Fig. 2 Full Scale AIM-9E Sidewinder Missile and WSE Pod

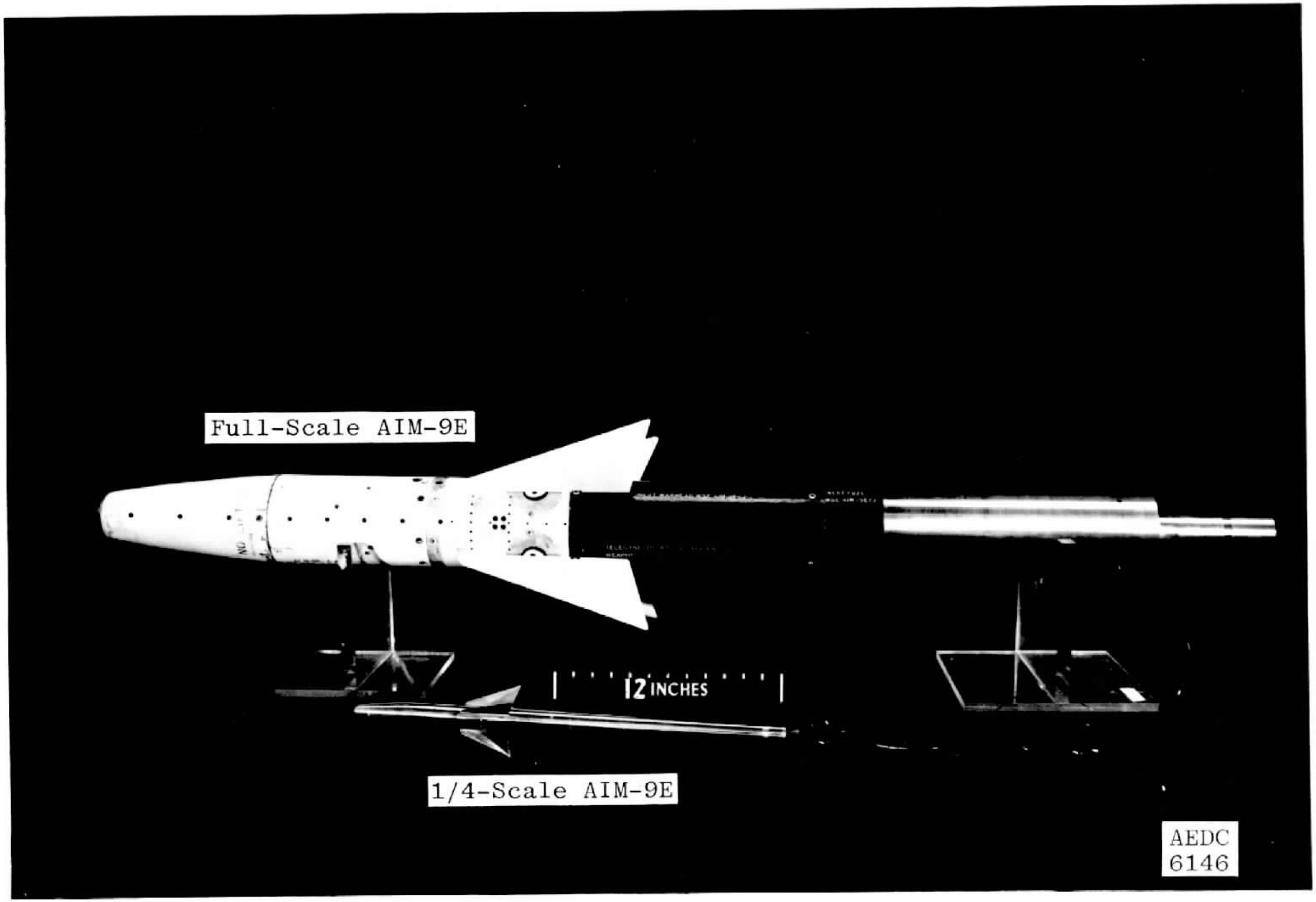


Fig. 3 Full- and 1/4-Scale AIM-9E Wind Tunnel Models

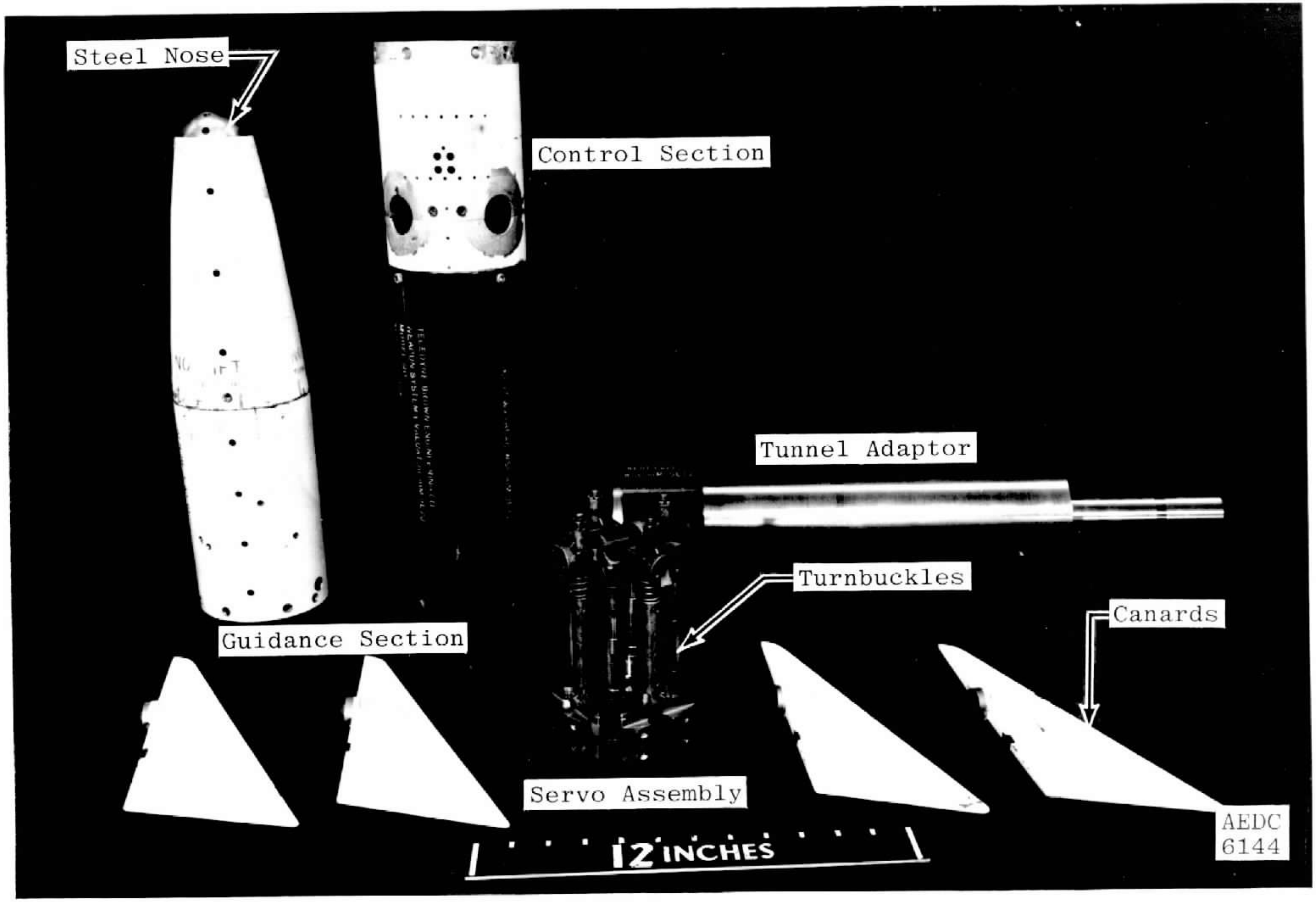


Fig. 4 Full-Scale AIM-9E Hardware Modifications

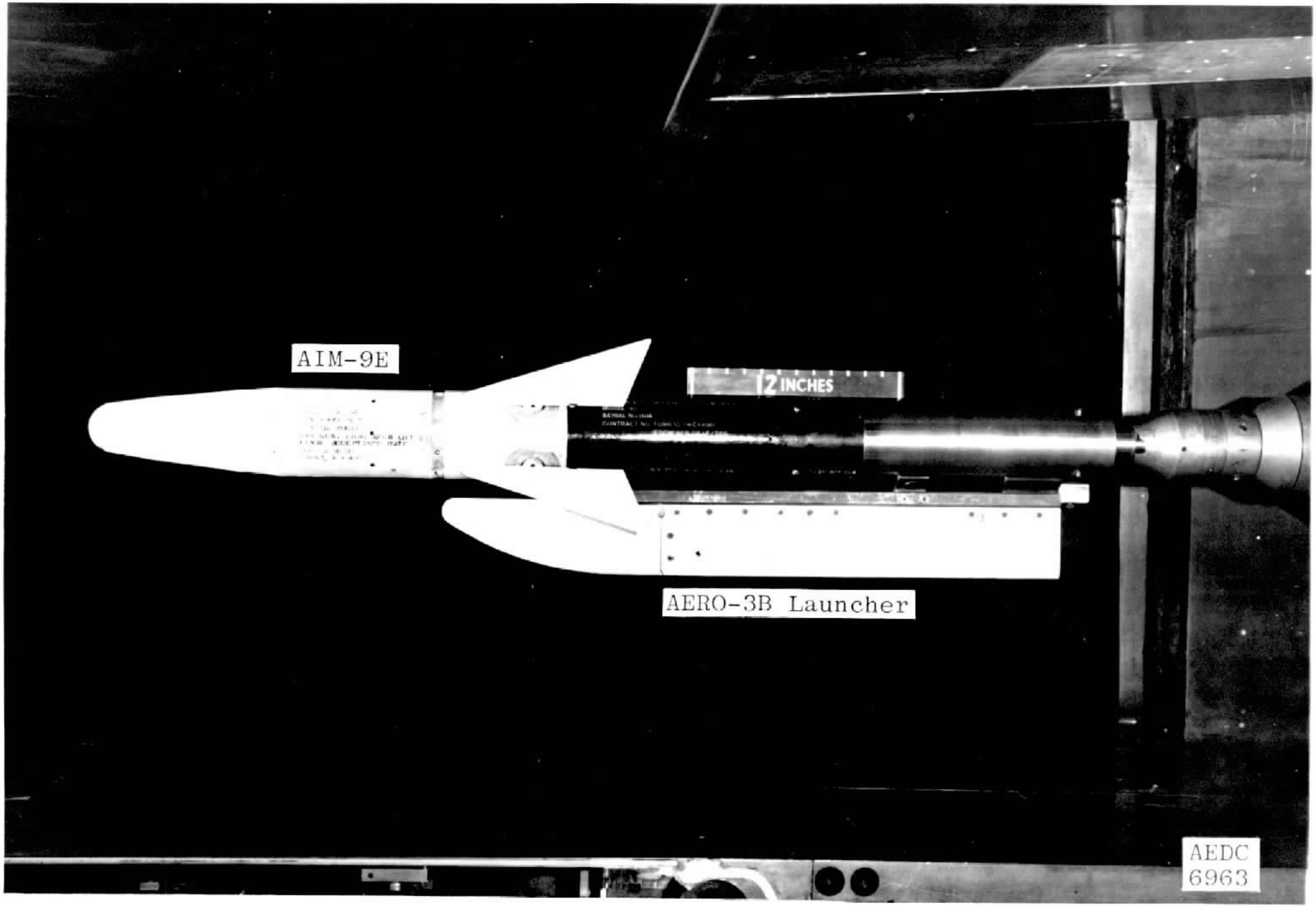


Fig. 5 Mated Full-Scale AIM-9E Missile and Launch Rail

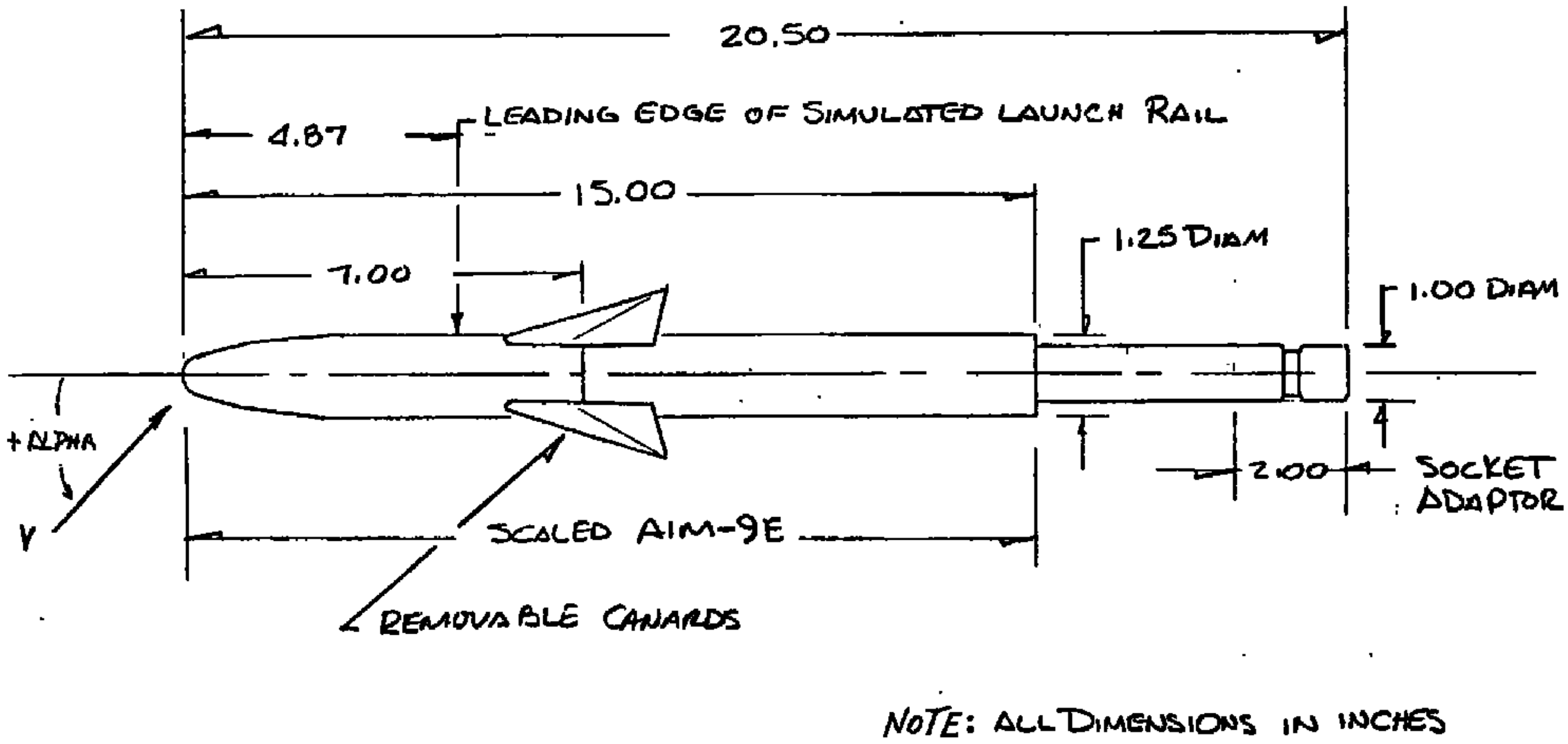


Fig. 6 1/4 Scale AIM-9E Sidewinder Missile Definition

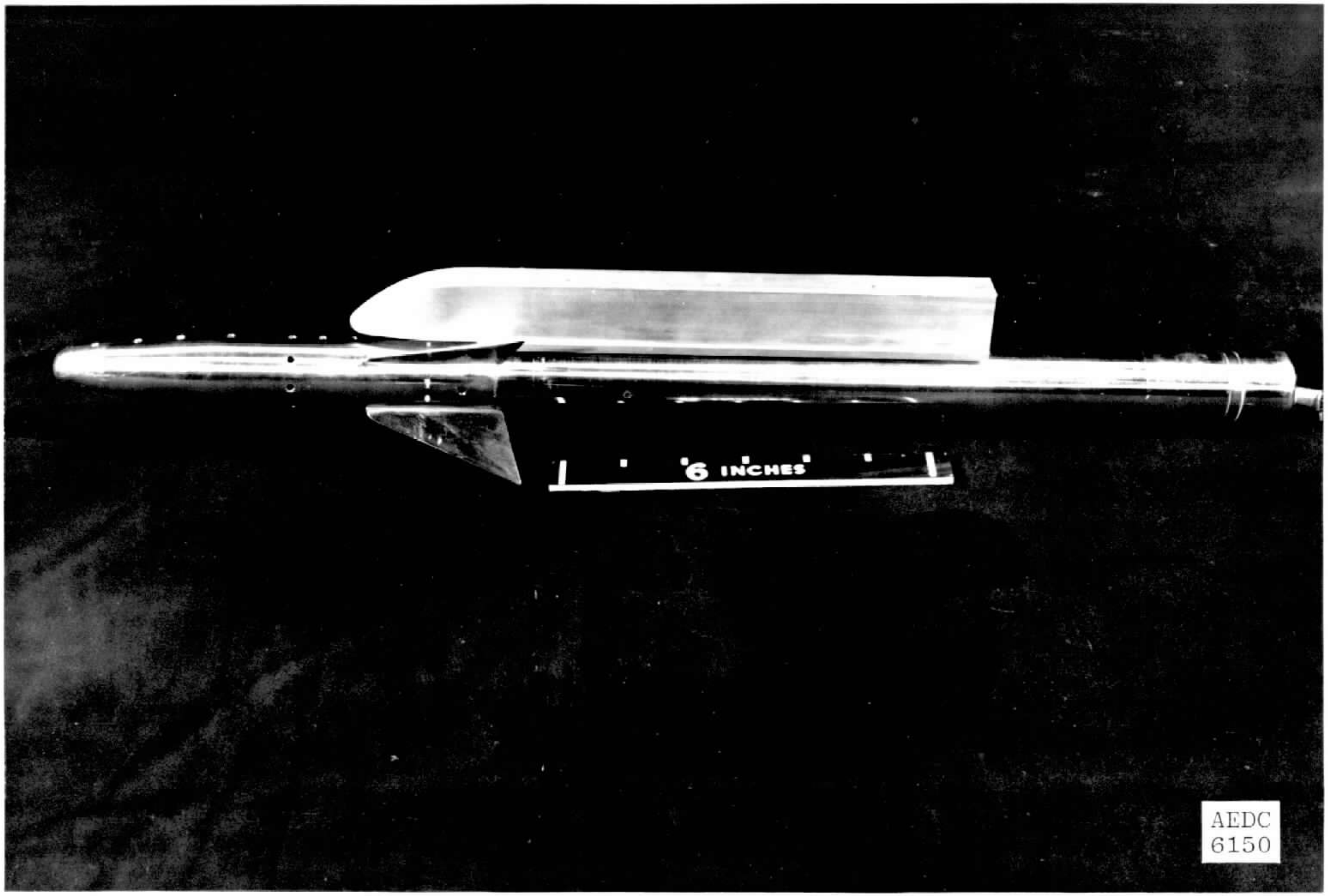


Fig. 7 Mated 1/4-Scale Missile and Launch Rail

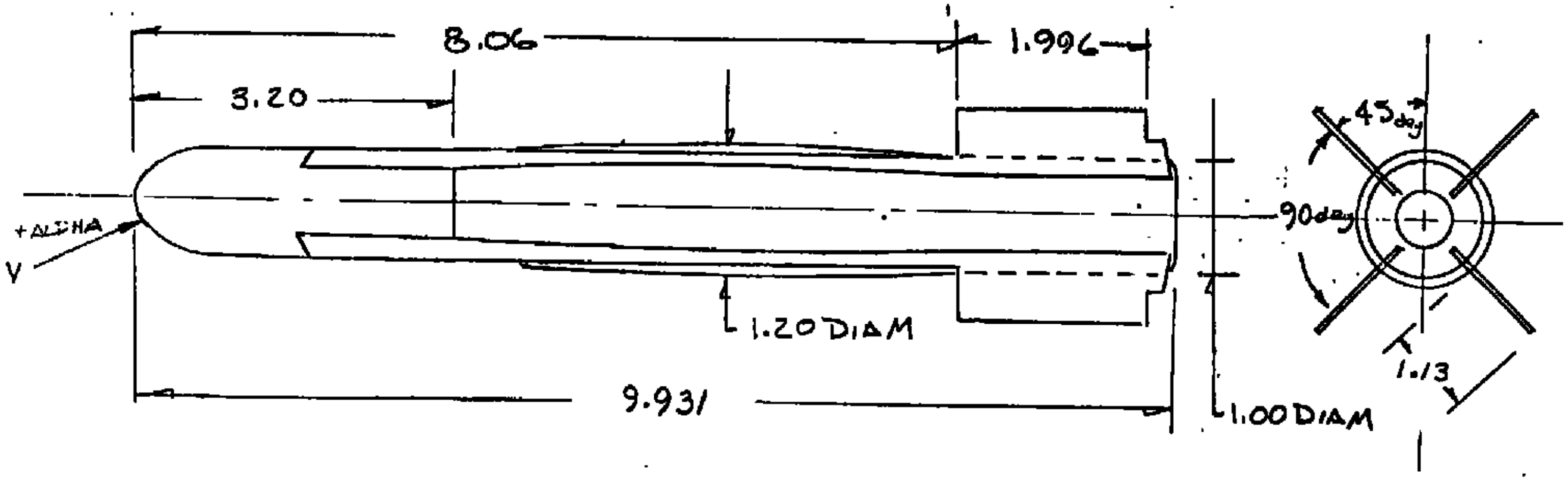


Fig. 8 1/15 Scale GBU-8 Guided Bomb Unit Definition

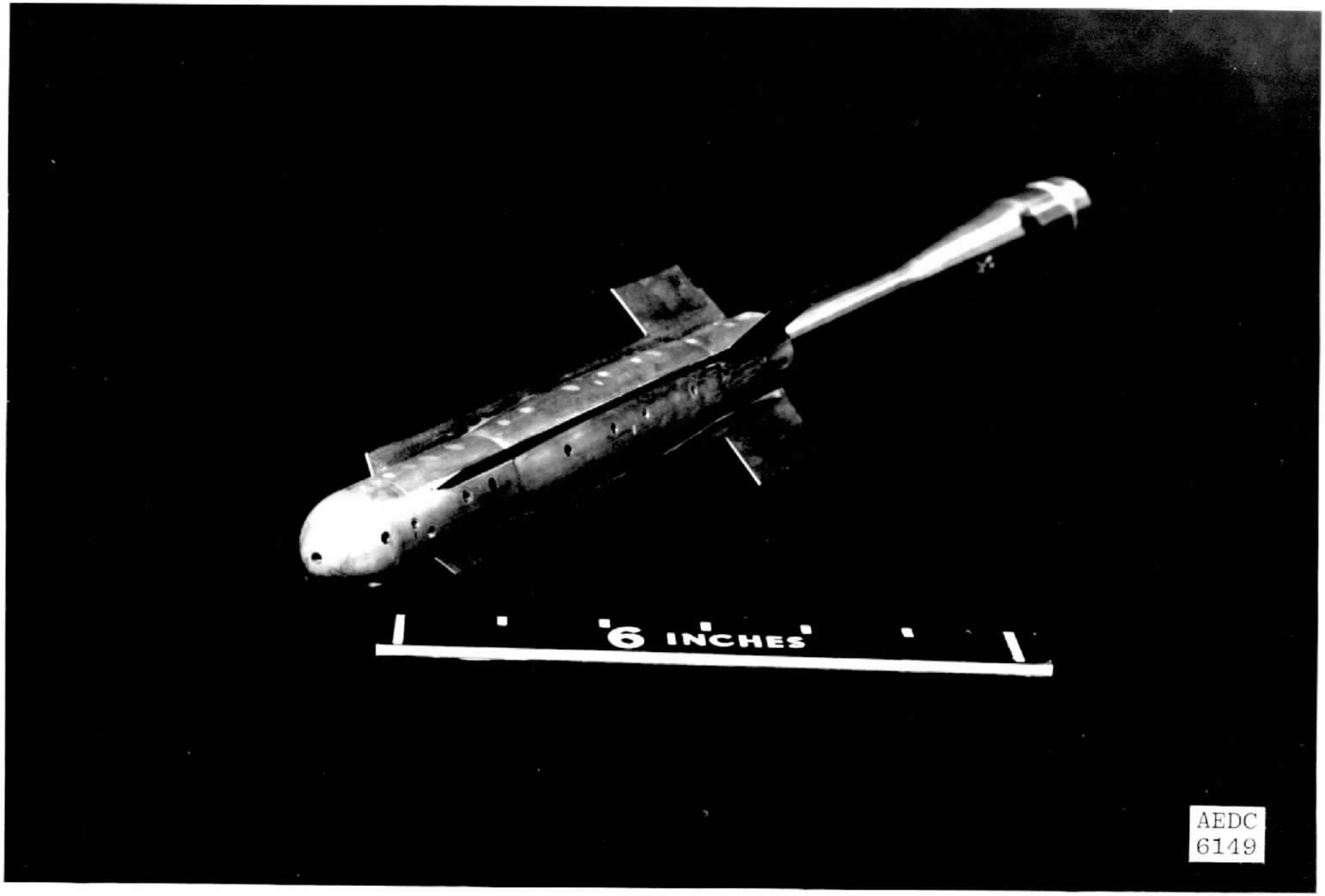


Fig. 9 1/15-Scale GBU-8 and Support Sting

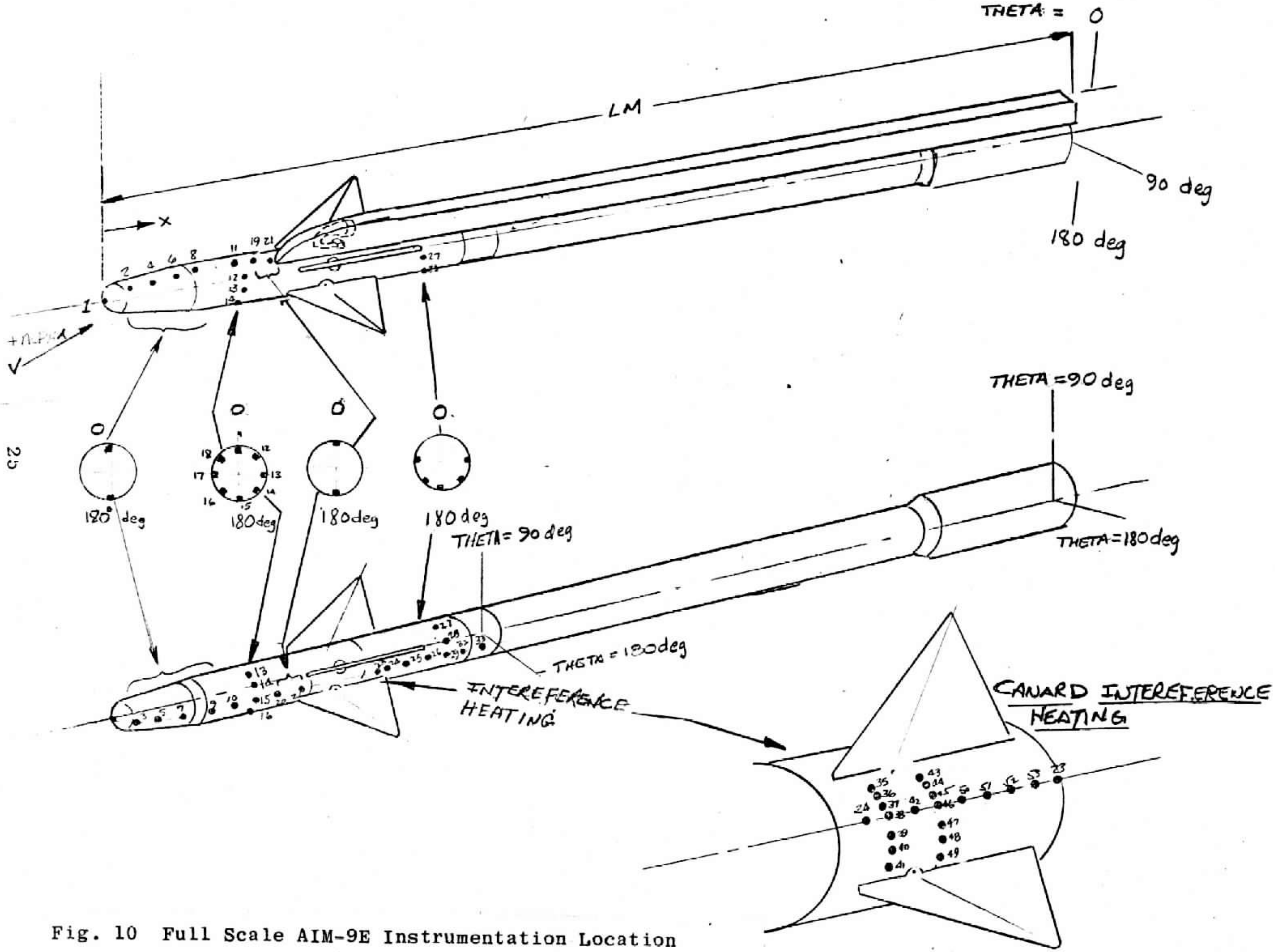


Fig. 10 Full Scale AIM-9E Instrumentation Location

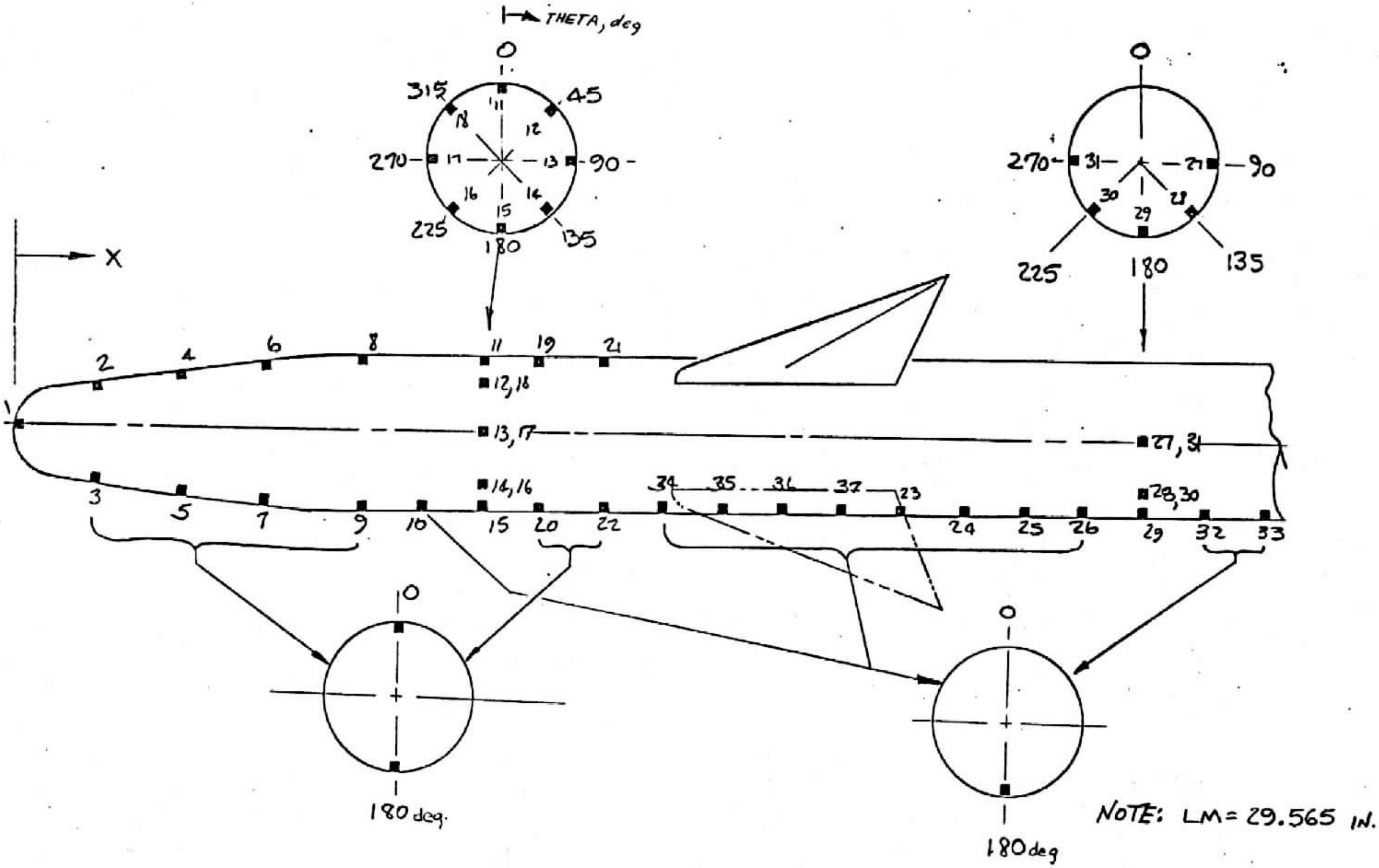


Fig. 11 1/4 Scale AIM-9E Instrumentation Location

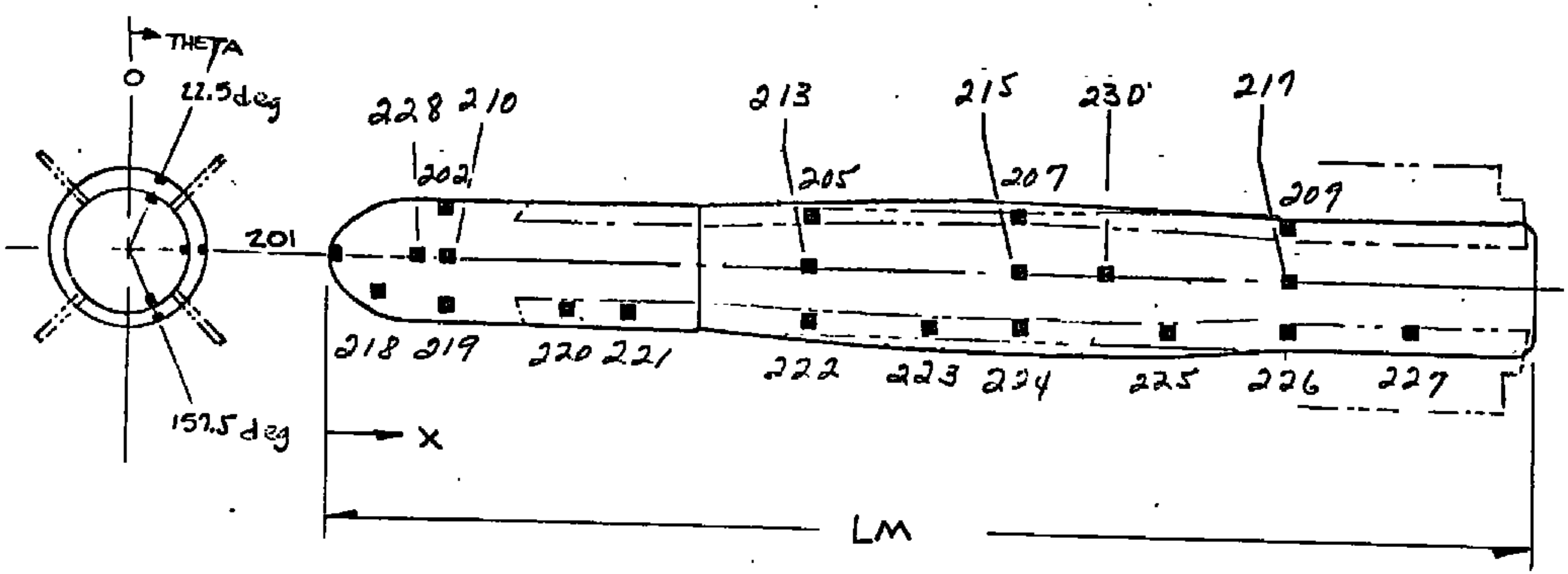


Fig. 12 1/15 Scale GBU-8 Instrumentation Location

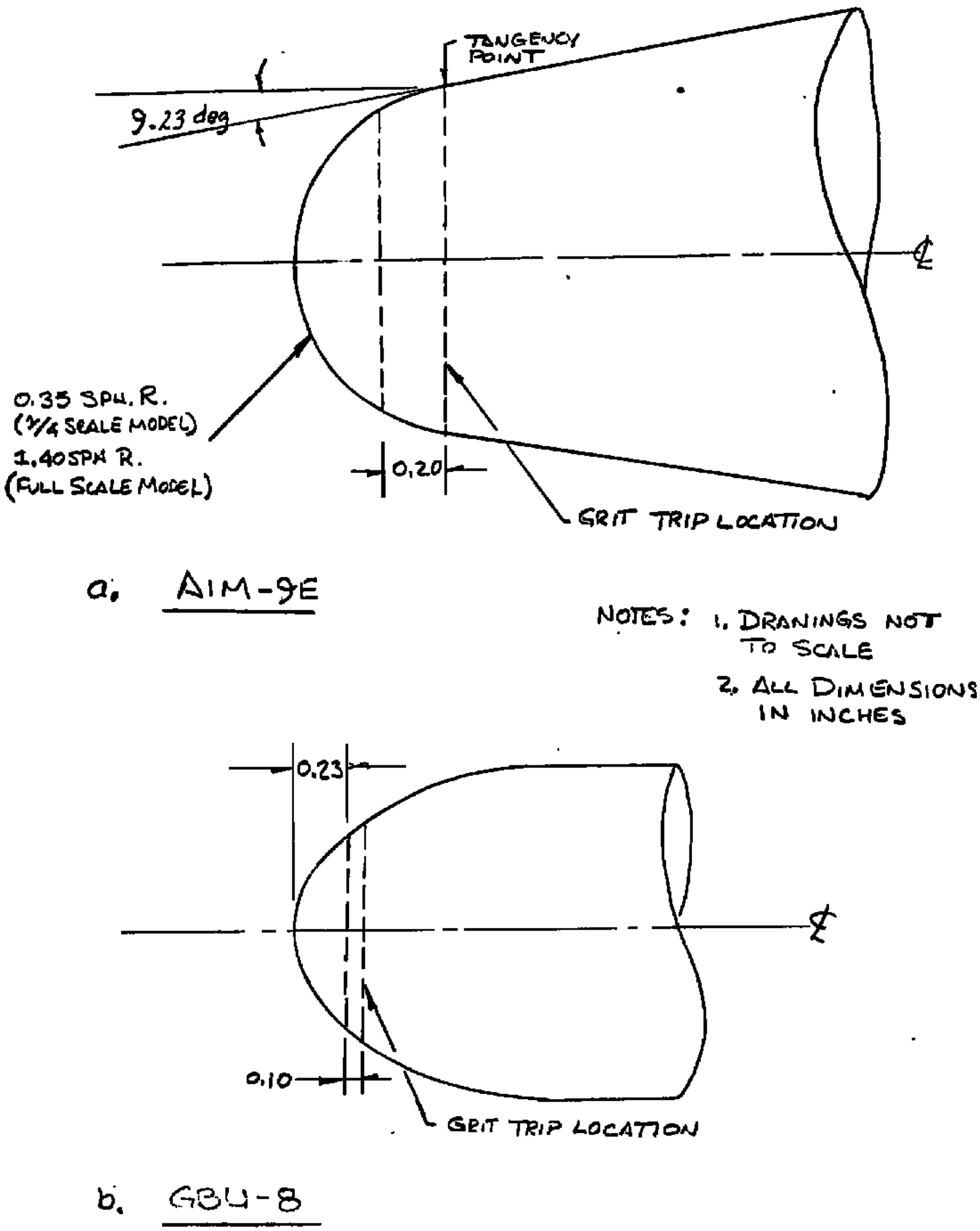


Fig. 13 Boundary Layer Trip Location

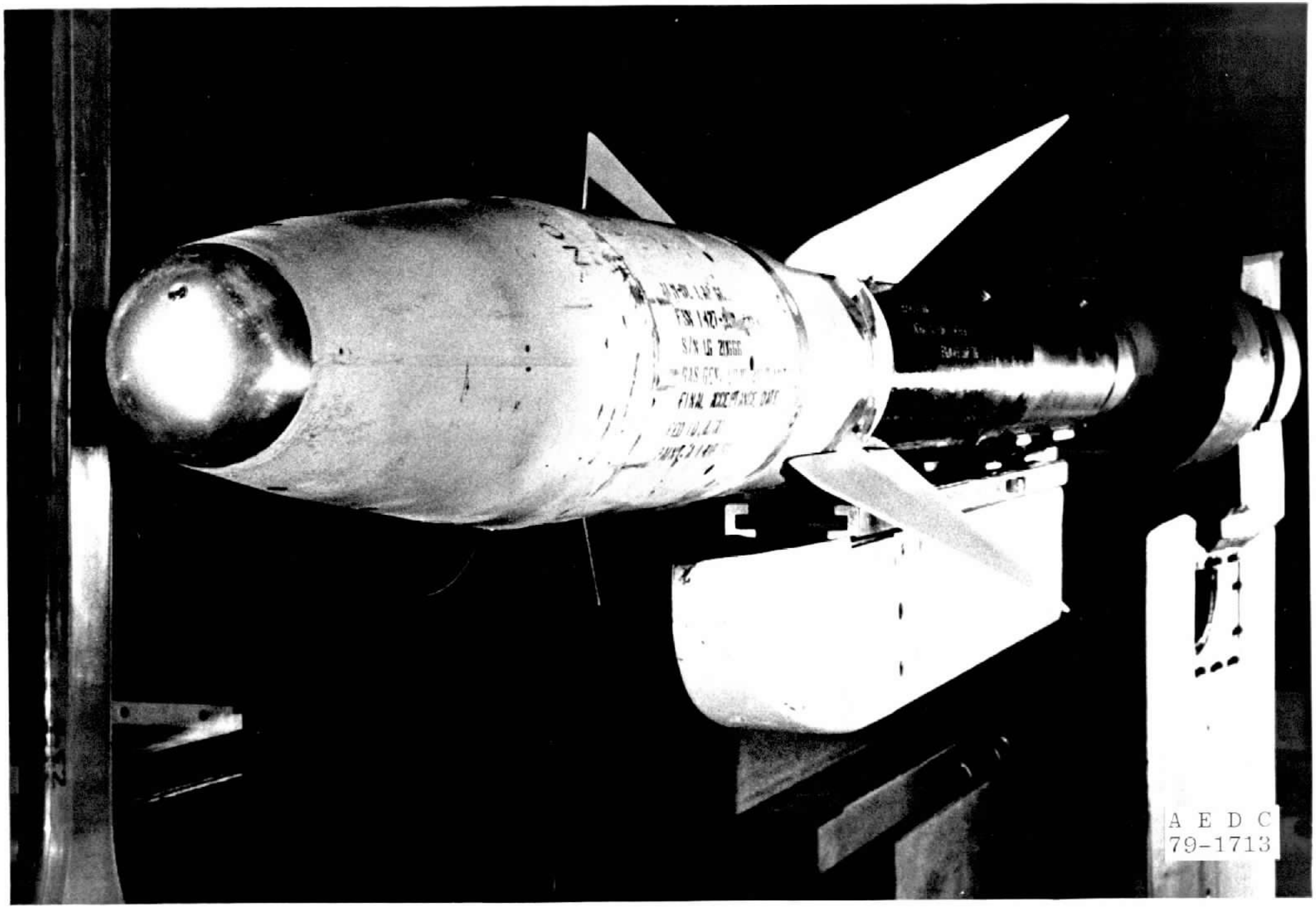


Fig. 14 Full-Scale AIM-9E Installation in Tunnel A

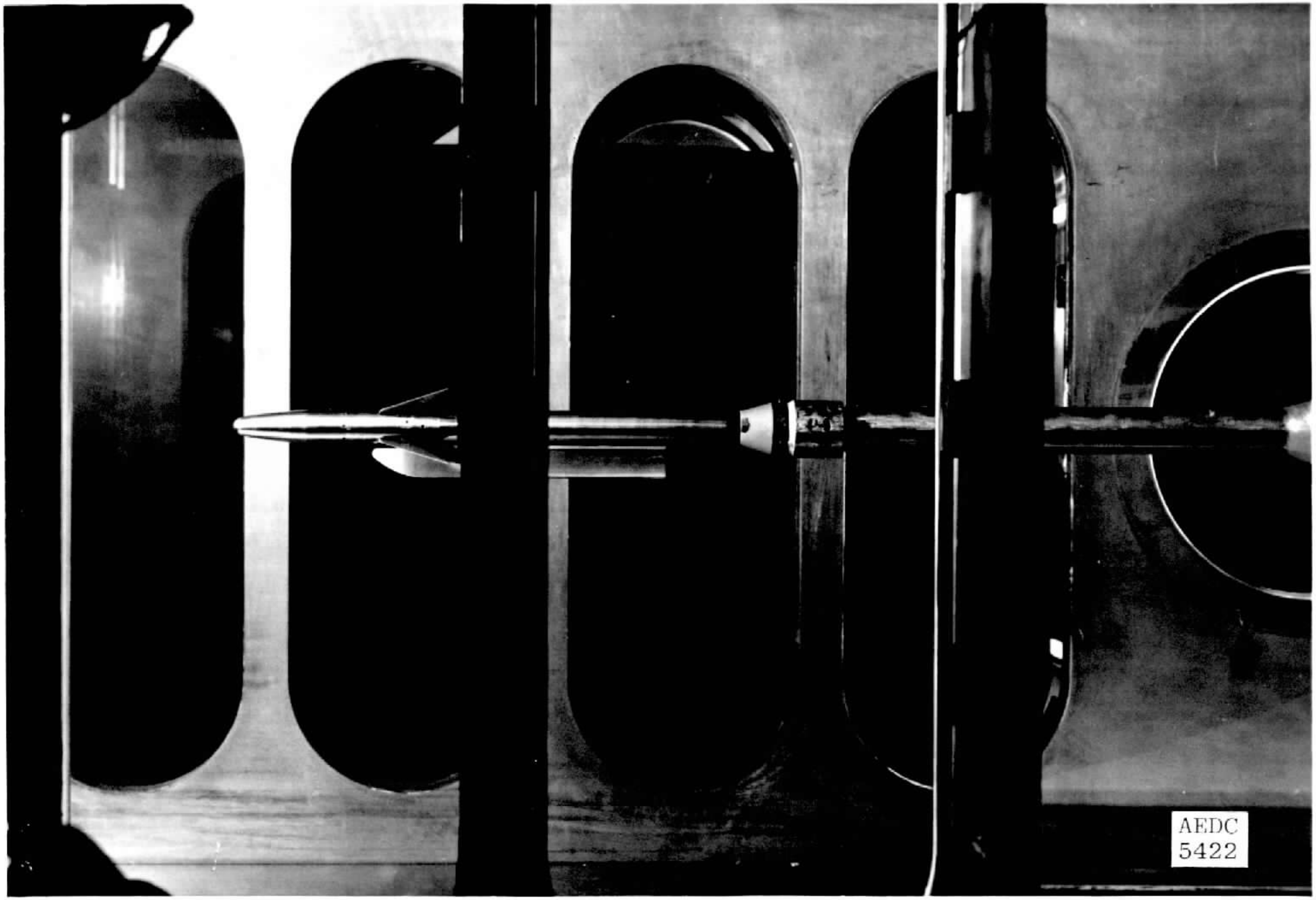


Fig. 15 1/4-Scale AIM-9E Installation in Tunnel A

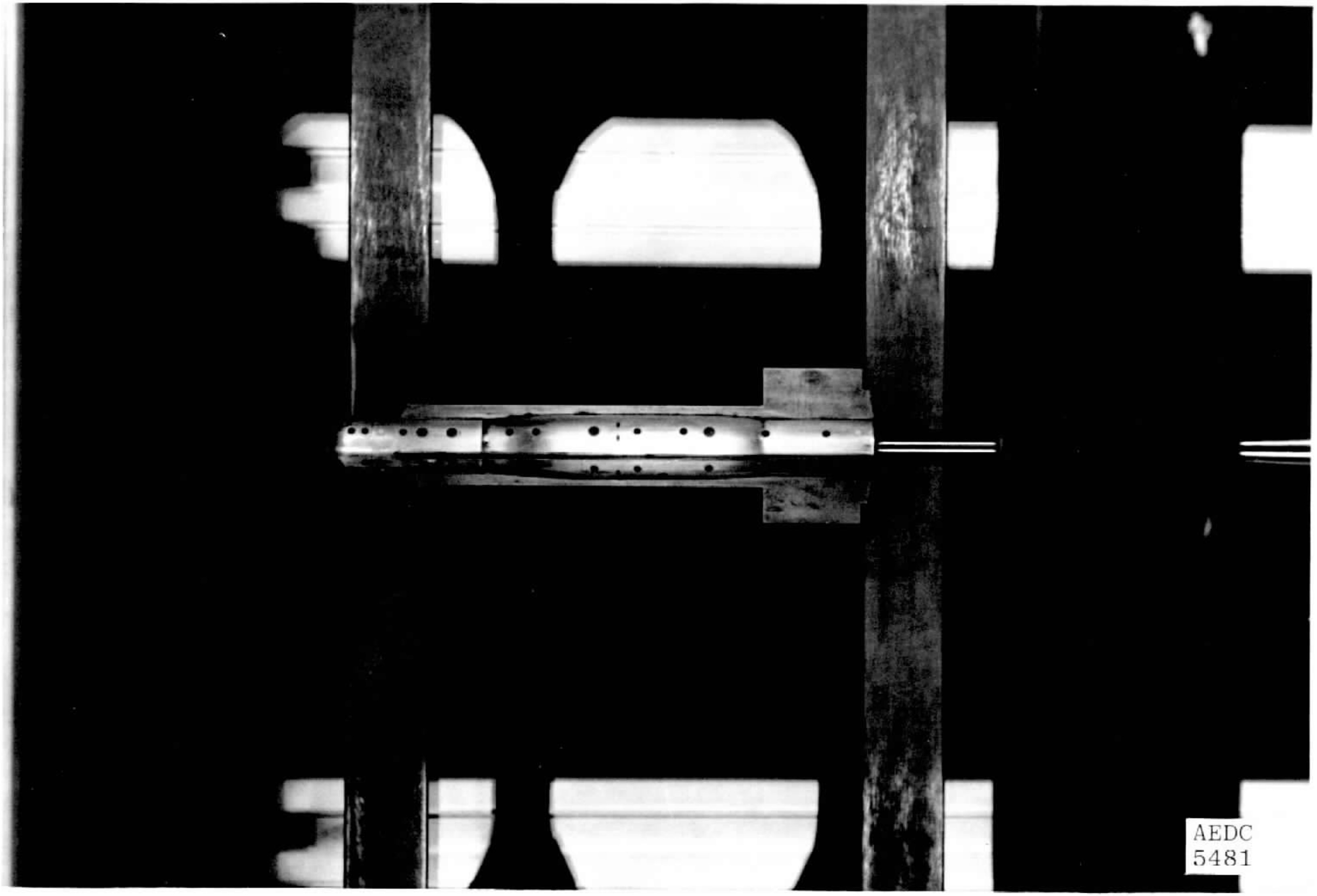


Fig. 16 1/15-Scale GBU-8 Installation in Tunnel A

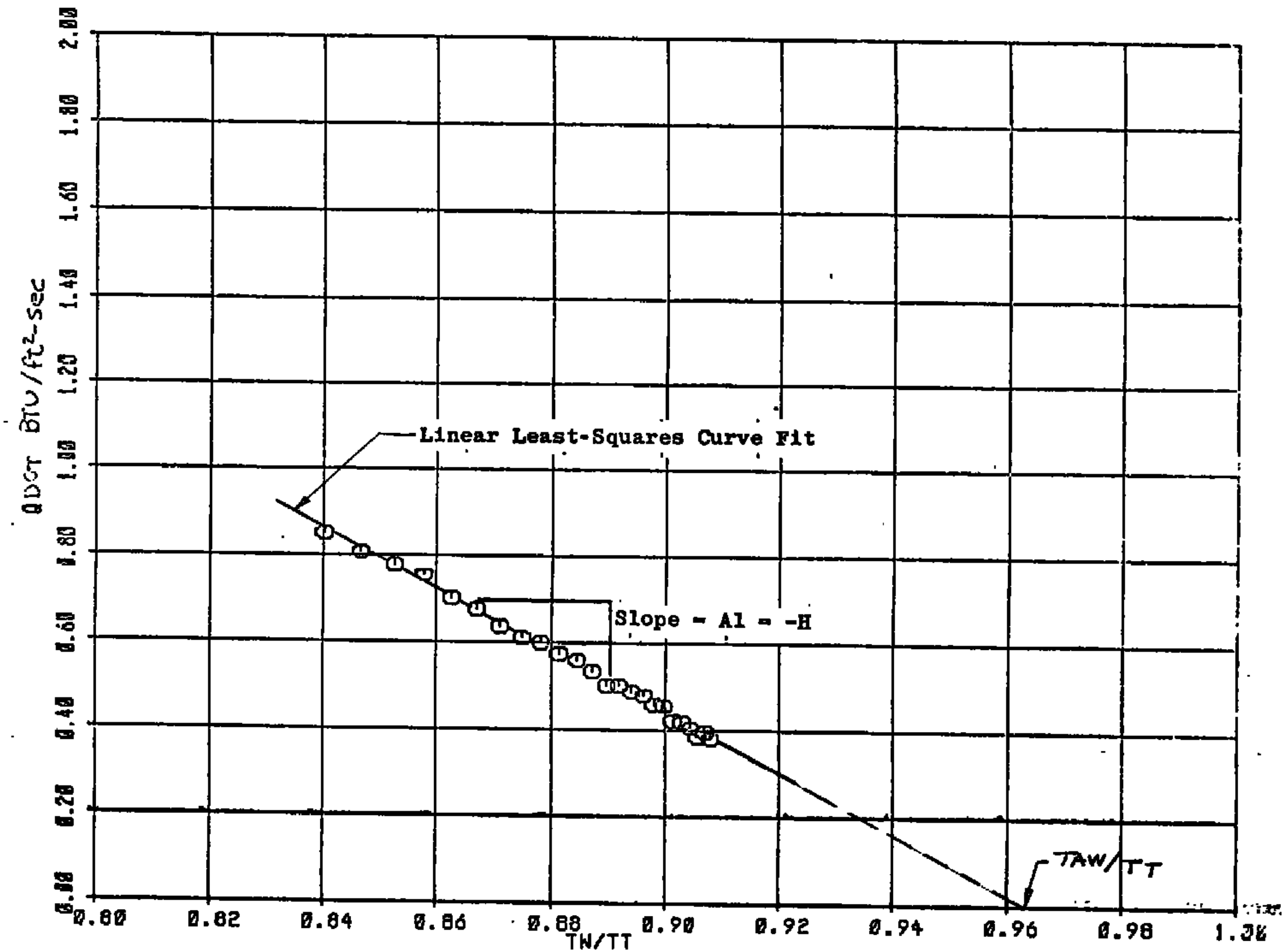
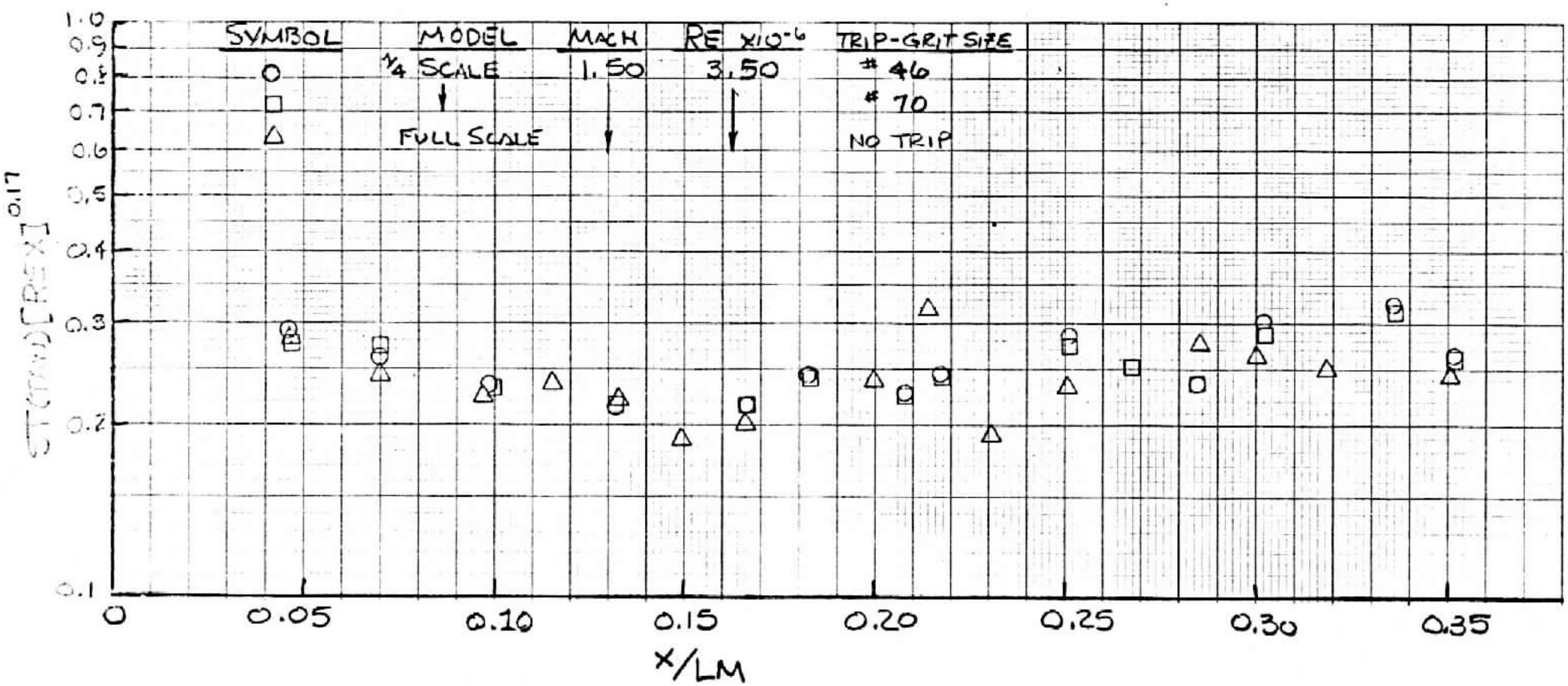


Fig. 17 Typical Plot of QDOT Versus TW/TT



33 FIG. 18 COMPARISON OF THE FULL AND 1/4 SCALE AIM-9E TUNNEL DATA

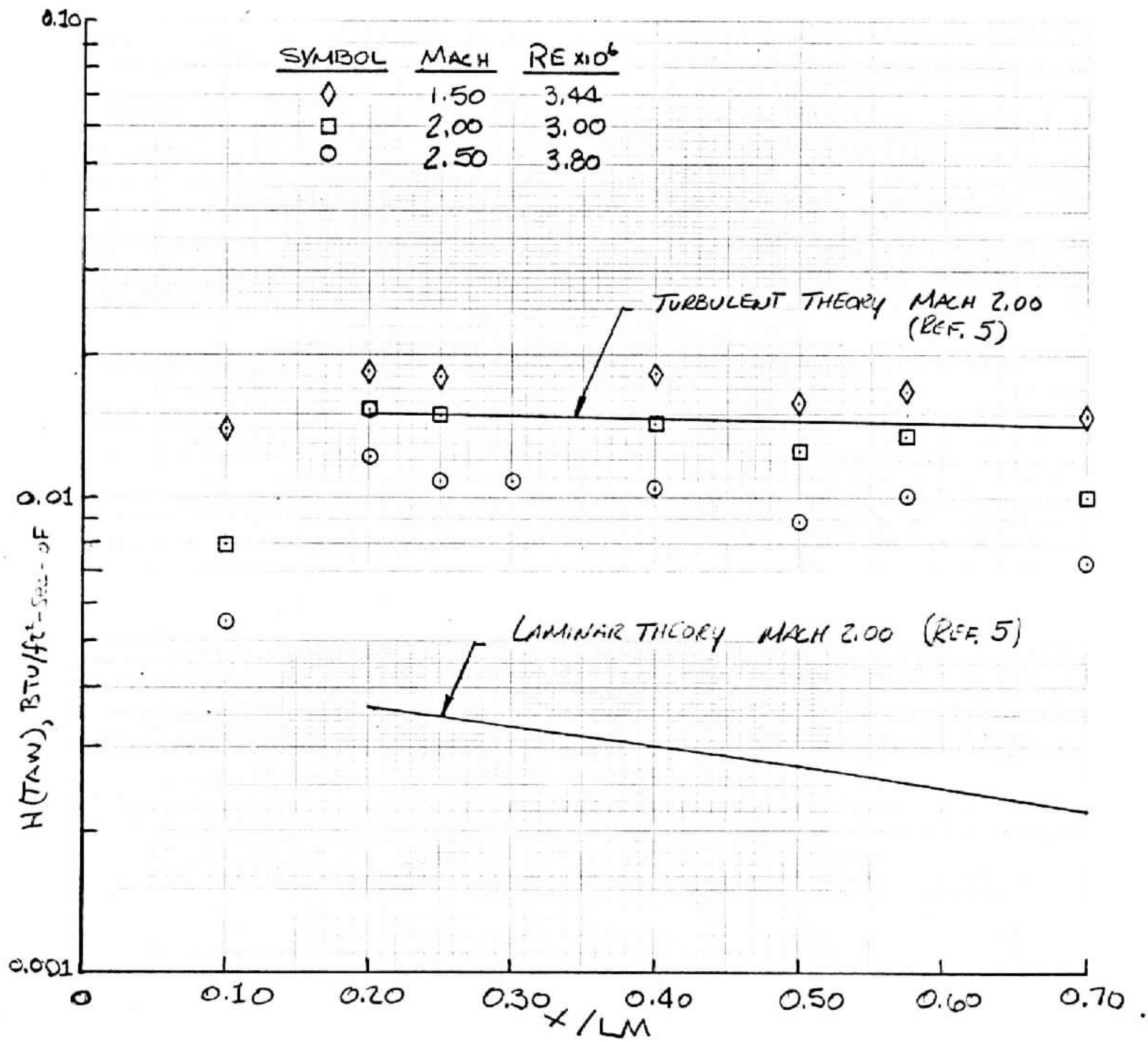


FIG. 17 GBU-8 HEATING DISTRIBUTION SUMMARY

APPENDIX II

TABLES

TABLE 1. MEASUREMENT UNCERTAINTIES

a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S) Percent of Reading	Precision Index (S) Unit of Measurement	Precision Index (S) Degree of Freedom	Bias (B) Percent of Reading	Bias (B) Unit of Measurement	Uncertainty $\pm(B + t_{95}S)$ Percent of Reading	Uncertainty $\pm(B + t_{95}S)$ Unit of Measurement	Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
ALPI,deg		±0.025	>30		0+		±0.05	±15	Potentiometer	Digital Data Acquisition System	Precision Inclinometer
PHII,deg		±0.2	>30		0+		±0.4	±180		Analog to Digital Converter	Gage Reading
PT,psia		±0.002 ±0.007	>30 >30	±0.2 ±0.2		±(0.2% + 0.004) ±(0.2% + 0.014)		5.5 to 15 15 to 60	Bell & Howell Variable Capacitance Transducer	Digital Data Acquisition System Analog to Digital Converter	In-Place Air Dead Weight Calibration
QDOT,BTU/FT²-SEC	±0.5 ±1.5		>30	±4 ±4		±5 ±7		1 to 3 0.2 to 1	Gardon Gage	Beckman 210 Digital to Analog Converter	VJ2 Laboratory
TGE,°F		±1.5	>30		0+		±3	50 to 200	Copper-Constantan and Iron-Constantan Thermocouples		Thermocouple Verification of NBS Conformity/Voltage Substitution Calibration
TT,°F		±1.5	>30		0+		±3	0 to 300	Copper-Constantan Thermocouple	Doric Temperature Instrument/Digital Multiplexer	Thermocouple Verification of NBS Conformity/Voltage Substitution Calibration

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

+Assumed to be zero

VB-16 (6/79)

TABLE 1 Concluded
b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S) Percent of Reading	Precision Index (S) Unit of Measurement	Precision Index (S) Degree of Freedom	Bias (B) Percent of Reading	Bias (B) Unit of Measurement	Uncertainty ±(B + t_{95}S) Percent of Reading	Uncertainty ±(B + t_{95}S) Unit of Measurement	Range M	Range H(TAW)
ALPHA, deg		±0.05			0+		±0.10	All	All
H(TAW), $\frac{BTU}{^{o}R\text{-}ft^{2}\text{-}sec}$	±2.5 ±5.0			±5 ±5		±10 ±15		All	>0.01 <0.01
M		±0.0125 ±0.0080 ±0.0060			0+ 0+ 0+		±0.025 ±0.016 ±0.012	1.5 2.0 2.5	All
PHI, deg		±0.20			0+		±0.40	All	All
RHO, lbm/ft^3	±1.3 ±0.9 ±0.7			±0.2 ±0.2 ±0.2		±2.8 ±2.0 ±1.6		1.5 2.0 2.5	All
RE, ft^{-1}	±0.4 ±0.5 ±0.5			±0.2 ±0.2 ±0.2		±1.0 ±1.2 ±1.2		1.5 2.0 2.5	All
ST(TAW)	±1.0 ±5.5			±5 ±5		±11 ±16		All	>0.01 <0.01
TAW, ^{o}R	±0.3 ±0.6			±0.2 ±0.2		±0.8 ±1.4		All	>0.01 <0.01
TW, ^{o}R		±1.6			0+		±1.6	All	All
V, ft/sec	±0.60 ±0.25 ±0.15			0+ 0+ 0+		±1.2 ±0.5 ±0.3		1.5 2.0 2.5	All

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

+Assumed to be zero

VB-16a (9-79)

TABLE 2
FULL SCALE AIM-9E INSTRUMENTATION LOG

GAGE	AXIAL LOCATION X (IN)	AXIAL LOCATION X/LM	CIRCUMFERENTIAL LOCATION THETA (deg)
1	0	0	STAG. PT.
2 ⊛	2.720	0.0230	0
3			180
4 ⊛	5.520	0.0468	0
5			180
6 ⊛	8.320	0.0705	0
7			180
8 ⊛	11.640	0.0968	0
9			180
10	13.640	0.1156	
11 *	15.640	0.1325	0
12			45
13			90
14			135
15			180
16			225
17			270
18			315
19	17.640	0.1495	0
20			180
21	19.640	0.1664	0
22			180
23	29.640	0.2512	
24 *	31.640	0.2681	
25	33.640	0.2850	
26	35.640	0.3020	
27	37.640	0.3189	90
28			135
29			180
	LM = 118 INCHES		

TABLE 2 (CONCLUDED)

GAGE	AXIAL LOCATION X (IN)	AXIAL LOCATION X/LM	CIRCUMFERENTIAL LOCATION THETA (deg)
30	37.640	0.3189	225
31			270
32	39.640	0.3359	180
33	41.640	0.3528	
34 *	20.246	0.1716	
35	21.246	0.1800	145.62
36			157.08
37			168.54
38			180.00
39			191.46
40			202.92
41			214.38
42 *	22.246	0.1885	180.00
43	23.246	0.1970	145.62
44			157.08
45			168.54
46			180.00
47			191.46
48			202.92
49			214.38
50 *	24.246	0.2055	180.00
51	25.246	0.2139	
52	26.246	0.2224	
53	27.246	0.2309	
54 ⊛	0.1876	0.0016	
55	0.700	0.0060	
	LM = 118 INCHES		

NOTES: 1, * DENOTES GAGES PERMANENTLY CONNECTED TO THE DCAP DATA SYSTEM.

2, ⊛ DENOTES THOSE GAGES ON THE QUICK DISCONNECT PLUG WHICH [illegible] CHANNELS BETWEEN [illegible] AND THE TUNNEL STANDARD DATA SYSTEM

TABLE 3

1/4 SCALE AIM-9E INSTRUMENTATION LOCATION

GAGE	AXIAL LOCATION X (IN)	AXIAL LOCATION X/LM	CIRCUMFERENTIAL LOCATION THETA (DEG)
1	0	0	STAG. POINT
2	0.680	0.0230	0
3	↓	↓	180
4	1.380	0.0468	0
5	↓	↓	180
6	2.080	0.0705	0
7	↓	↓	180
8	2.910	0.0986	0
9	↓	↓	180
10	3.410	0.1156	↓
11	3.910	0.1325	0
12	↓	↓	45
13	↓	↓	90
14	↓	↓	135
15	↓	↓	180
16	↓	↓	225
17	↓	↓	270
18	↓	↓	315
19	4.410	0.1495	0
20	↓	↓	180
21	4.910	0.1664	0
22	↓	↓	180
23	7.410	0.2511	↓
24	7.910	0.2681	↓
25	8.410	0.2850	↓
26	8.910	0.3020	↓
27	9.410	0.3189	90
28	↓	↓	135
	LM = 29.565 INCHES		

TABLE 3 (CONCLUDED)

GAGE	AXIAL LOCATION X (IN)	AXIAL LOCATION X/LM	CIRCUMFERENTIAL LOCATION THETA (DEG)
29	9.410	0.3189	180
30			225
31			270
32	9.910	0.3359	180
33	10.410	0.3528	
34	5.410	0.1833	
35	5.910	0.2003	
36	6.410	0.2172	
37	6.910	0.2342	

LM= 29.565 INCHES

TABLE 4

1/15 SCALE GBU-8 INSTRUMENTATION LOCATION

GAGE	AXIAL LOCATION X (IN)	X/LM	CIRCUMFERENTIAL LOCATION THETA (DEG)
201	0	0	STAG. POINT
202	1.00	0.1007	22.5
205	4.00	0.4028	
207	5.75	0.5790	
209	8.00	0.8056	
228	0.75	0.0755	90.0
210	1.00	0.1007	
213	4.00	0.4028	
215	5.75	0.5790	
230	6.50	0.6546	
217	8.00	0.8056	
218	0.50	0.0503	157.5
219	1.00	0.1007	
220	2.00	0.2014	
221	2.50	0.2518	
222	4.00	0.4028	
223	5.00	0.5035	
224	5.75	0.5790	
225	7.00	0.7049	
226	8.00	0.8056	
227	9.00	0.9063	

LM = 9.930 INCHES

Table 5. Test Log

Run	Configuration Code	M	RE $\times 10^6$	PT psia	TT °F	ALPHA deg	PHI deg	TRIP	TRIP SIZE	OIL FLOW	TYPE OIL	Time	Remarks
1	AIM-9E w/	2.50	3.81	24	180	0	180	YES	#46	NO	—		
2	NO CANARDS												
3	OR LAUNCHER						0						
4			5.00	32			180						
5			3.80	24				NO	—				
6			5.00	32					—				
7		2.00	4.18	21				YES	#46				
8			3.45	17									
9		1.51	3.52	14.5									
10									#70				
11	AIM9E +												
12	CANARDS &					-2							
13	LAUNCHER					2							
14						4							
15		2.00	4.18	20.5		0							
16			3.64	18		-2							
17						0							
18						2							
19						4							
20			3.71			0							

NOMENCLATURE

NOTES : 1. CANARD DEFLECTION ANGLE = 0 DEG.
2. MODEL YAW ANGLE = 0 DEG (ALL RUNS)

Table 5. Test Log

Run	Configuration Code	M	RE $\times 10^6$	PT psia	TT °F	ALPHA deg	PHI deg	TRIP	TRIP SIZE	OIL FLOW	TYPE OIL	Time	Remarks
21	AIM-9E +	2.00	4.77	19.5	100	0	180	YES	#70	YES	MED.		
22	CANARDS &										HEAVY		
23	LAUNCHER										EXTRA HEAVY		
24						4							
25		1.50	4.07	14		0							
26						4							
27	GBU-8	2.50	3.81	24	180	0	0	YES	#70	NO	–		
28							180						
29			5.10	32			0						
30						4							
31		2.00	4.15	20.5		0							
32						4							
33			3.67	18		0							
34			4.14	20.5		4	-90						
35							90						
36		1.51	3.44	14.5		0	0						
37			3.25	13.4		4	-90						
38							90						
39		2.00	3.00	15		0	0	NO	–				

NOMENCLATURE

NOTES: 1. CANARD DEFLECTION ANGLE = 0 DEG.
2. MODEL YAW ANGLE = 0 DEG (ALL RUNS)

Table 5. Test Log

Run	Configuration Code	M	RE $\times 10^{-6}$	PT psia	T_T °F	ALPHA deg.	PHI deg.	TRIP	TRIP SIZE	OIL FLOW	TYPE OIL	Time	Remarks
[illegible]	AIM-9E	2.50	5.0	32	180	0	180	YES	#150	NO	—		
[illegible]	(NO CANARDS	2.38	1.3	8									
[illegible]	& LAUNCHER)	2.50	3.6	23									
[illegible]		2.38	1.3	8		4							
[illegible]		1.84	0.9	4		0							
[illegible]		1.50	0.9	5									
[illegible]			3.6	14.5				No	—				
45			3.3	10.2									
[illegible]		2.00	4.2	19									
[illegible]	+DCAP		3.6	18									CONNECT NOSE GAGES TO DCAP RECORDER
[illegible]			4.2	20									
49	AIM-9 – DCAP	2.50	5.0	32									SWITCH DCAP NOSE GAGES BACK TO TUNNEL A DATA SYSTEM
[illegible]	(NO CANARDS	2.38	1.3	8									
[illegible]	& LAUNCHER)	2.50	3.6	23									
[illegible]	AIM-9+(CANARDS		5.0	32									INSTALLED CANARDS AND LAUNCHER CANARD DEFLECTION = 0 deg.
[illegible]	+ LAUNCHER)	2.00	4.2	20									
[illegible]						4							
[illegible]			3.6	18		0							
[illegible]						2							
[illegible]						4							

NOMENCLATURE

NOTES:

1. CANARD DEFLECTION ANGLE = 0 deg.
2. MODEL YAW ANGLE = 0 deg.

Table 5. Test Log

Run	Configuration Code	M	RE x10⁶	PT psia	TT °F	ALPHA deg.	PHI deg	TRIPS	TRIP SIZE	OIL FLOW	TYPE OIL	Time	Remarks
58	AIM-9E	1.50	3.6	14.5	180	0	180	NO	—	—	—		
59	+(CANARDS +	↓	↓	↓	↓	2	↓	↓	↓	↓	↓		
60	LAUNCHER)	↓	↓	↓	↓	4	↓	↓	↓	↓	↓		

NOMENCLATURE

APPENDIX III

SAMPLE TABULATED DATA

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE

DATE COMPUTED 11-JUL-79
TIME COMPUTED 13:34:02
DATE RECORDED 7-JUN-79
TIME RECORDED 0:21:46
PROJECT NUMBER V41A-48

RUN	MODEL	MACH NUMBER	PT (PSIA)	PT2 (PSIA)	TT (DEGR)	ALPHA	ROLL	ST(TAW)O	NO CANARDS
9	AIM-9E	1.51	14.5	13.4	638.67	0.00	180.04	3.310E-03	

T (DEGR)	P (PSIA)	Q (PSIA)	V (FT-SEC)	RHO (LBS/FT3)	MU (LB-SEC/FT2)	RE (FT-1)	HFR (RW=.02917FT)	STFR (RW=.02917FT)
438.64	3.88	6.192	1550.	2.387E-02	3.273E-07	3.515E+06	4.182E-02	4.714E-03

GAGE	TAW	TAW/ TT	H(TAW)	ST(TAW)	ST(TAW) /ST(TAW)O	REX	GAGE LOCATION X	X/LM	THETA
1	647.645	1.014	2.938E-02	3.310E-03	1.000E+00	0.000E+00	0.000	0.0000	0.00
2	610.256	0.956	2.743E-02	3.098E-03	9.358E-01	1.992E+05	0.680	0.0230	0.00
4	619.325	0.970	2.348E-02	2.650E-03	8.004E-01	4.042E+05	1.380	0.0468	0.00
5	623.117	0.976	2.892E-02	3.263E-03	9.856E-01	4.042E+05	1.380	0.0468	180.00
6	620.085	0.971	2.172E-02	2.451E-03	7.404E-01	6.093E+05	2.080	0.0705	0.00
7	624.630	0.978	2.426E-02	2.737E-03	8.267E-01	6.093E+05	2.080	0.0705	180.00
9	626.914	0.982	2.047E-02	2.309E-03	6.976E-01	8.524E+05	2.910	0.0986	180.00
11	623.481	0.976	1.773E-02	2.000E-03	6.042E-01	1.145E+06	3.910	0.1325	0.00
12	618.250	0.968	2.106E-02	2.377E-03	7.182E-01	1.145E+06	3.910	0.1325	45.00
13	617.752	0.967	2.003E-02	2.260E-03	6.828E-01	1.145E+06	3.910	0.1325	90.00
14	619.354	0.970	1.829E-02	2.065E-03	6.237E-01	1.145E+06	3.910	0.1325	135.00
15	619.192	0.970	1.785E-02	2.015E-03	6.087E-01	1.145E+06	3.910	0.1325	180.00
17	617.727	0.967	1.875E-02	2.116E-03	6.393E-01	1.145E+06	3.910	0.1325	270.00
18	618.687	0.969	2.151E-02	2.428E-03	7.333E-01	1.145E+06	3.910	0.1325	315.00
19	628.442	0.984	1.883E-02	2.124E-03	6.417E-01	1.292E+06	4.410	0.1495	0.00
21	624.335	0.978	2.100E-02	2.369E-03	7.157E-01	1.438E+06	4.910	0.1664	0.00
22	619.748	0.970	1.738E-02	1.962E-03	5.926E-01	1.438E+06	4.910	0.1664	180.00
23	629.202	0.985	2.137E-02	2.411E-03	7.283E-01	2.170E+06	7.410	0.2511	180.00
24	627.010	0.982	1.862E-02	2.101E-03	6.346E-01	2.317E+06	7.910	0.2681	180.00
25	614.736	0.963	1.725E-02	1.948E-03	5.883E-01	2.463E+06	8.410	0.2850	180.00
26	625.485	0.979	2.180E-02	2.459E-03	7.429E-01	2.610E+06	8.910	0.3020	180.00
27	625.863	0.980	1.907E-02	2.152E-03	6.499E-01	2.756E+06	9.410	0.3189	90.00
28	625.003	0.979	1.756E-02	1.981E-03	5.983E-01	2.756E+06	9.410	0.3189	135.00
30	615.982	0.964	1.565E-02	1.766E-03	5.336E-01	2.756E+06	9.410	0.3189	225.00
32	620.604	0.972	2.349E-02	2.651E-03	8.009E-01	2.903E+06	9.910	0.3359	180.00
33	614.513	0.962	1.863E-02	2.103E-03	6.352E-01	3.049E+06	10.410	0.3528	180.00
34	622.093	0.974	1.925E-02	2.173E-03	6.563E-01	1.585E+06	5.410	0.1833	180.00
35	617.281	0.967	1.765E-02	1.992E-03	6.019E-01	1.731E+06	5.910	0.2083	180.00
36	621.062	0.972	1.881E-02	2.123E-03	6.412E-01	1.878E+06	6.410	0.2172	180.00

LOOP 4 TO 32 WAS USED IN CURVE FIT (29 POINTS)

APPENDIX IV

REFERENCE HEAT-TRANSFER COEFFICIENT AND STANTON NUMBER

In presenting heat-transfer coefficient results, it is convenient to use reference coefficients to normalize the data. Equilibrium stagnation point values derived from the work of Fay and Riddell (Ref. 6) were used to normalize the data obtained in this test. These reference coefficients are given by:

$$HFR = \frac{8.17173(PT2)^{0.5}(MUTT)^{0.4}\left[1 - \frac{P}{PT2}\right]^{0.25}\left[0.2235 + (1.35x10^{5})(TT + 560)\right]}{(RN)^{0.5}(TT)^{0.15}}$$

where

PT2	Stagnation pressure downstream of a normal shock wave, psia
MUTT	Viscosity conditions based on stagnation temperature, $lbf\text{-}sec/ft^2$
P	Free-stream pressure, psia
TT	Tunnel stilling chamber temperature, °R
RN	Reference nose radius, ft
RHO	Free-stream density, lbm/ft^2
V	Free-stream velocity, ft/sec

$$STFR = \frac{HFR}{(RHO)(V)[0.2235 + 0.0000135(TT + 560)](32.174)}$$